OU1 Cap Design Summary Document

1. Introduction

A summary of the OU1 engineered cap design is presented here, and further details and discussion are presented in the OU1 Cap Design Document, Revision 2 (Foth, 2007).

The OU1 Optimized Remedy includes an engineered cap to be placed over 112 acres of sediment area in OU1. The plan involves placing a 13-inch engineered cap over undredged sediments with an average PCB concentration between 2 and 10 ppm in the top 8-inch interval. The 13-inch cap thickness is considered to be comprised of 6-inches of sand and 7-inches of armor, with each media layer including a 3-inch overplacement allowance. The minimum design thickness of 7 inches is considered to be comprised of 3 inches of sand and 4 inches of armor.

Cap design was influenced by cap design criteria and guidance and OU1 specific cap design considerations. OU1 specific cap design considerations have been drafted with careful consideration of OU1 sediment characteristics, review of cap design addressed for the Lower Fox River OU2-5 project (Shaw and Anchor, 2006), and other attributes of the OU1 Design Supplement, such as dredging and sand cover. In addition, cap design has been influenced by a series of cap design workgroup meetings and correspondence with the Agencies and Oversight Team (A/OT).

This summary addresses the cap design with the following organization. Section 2 addresses the cap design approach, guidance and OU1 specific design criteria. Section 3 addresses key elements of the cap design, particularly,

- a summary of targeted and minimum cap layer thicknesses
- operational thickness, concept of target thickness and minimum design thickness
- properties and expected interactions of cap media with the sediment to be capped, including considerations of consolidation and settlement, geotechnical stability, and mixing layer characteristics
- chemical isolation considerations, including a summary of chemical isolation modeling and monitoring considerations
- media gradation considerations for the armor and sand layers
- bioturbation layer considerations
- erosion layer considerations, including resistance to various forces, including propeller wash, extreme flow events, extreme wind-wave events, and ice scour

Section 4 presents a summary of placement, monitoring, and quality assurance considerations.

2. Cap Design Approach and Criteria

Engineered capping of contaminated sediments requires long-term physical, biological, and chemical isolation of contaminated sediments. The design of engineered caps must be appropriately conservative, such that there is a reasonable level of assurance that the cap is designed, installed, monitored, and maintained for long-term performance. Caps need to resist natural and human-induced erosive forces that are expected to act on the cap. These erosive forces include 100-yr. flood event flows, high wind-wave conditions, propeller action from boating (prop wash), and ice scour.

The proposed cap design, monitoring, and maintenance plan are developed so that there is a high probability of achieving long-term physical stability and physical/chemical isolation of the cap. Guidance for cap design, specifically, cap thickness and media selection in order to achieve chemical and physical isolation were followed for OU1. (Palermo, *et al.* 1998b, Palermo, *et al.* 2002).

The overall protectiveness of the cap design depends not only on the susceptibility to damage and the potential impacts, but on whether that damage can be detected and appropriately corrected as part of planned monitoring and maintenance operations. The general preference of the proposed cap design, however, was to provide a high level of protectiveness against activities or processes that would impair the function of the cap. In addition, the proposed cap design does not rely on significant institutional controls in order to reach the intended overall protectiveness.

OU1 specific cap design considerations generally controlled the extent of the proposed cap areas. These are summarized below.

2.1 OU1 specific cap design considerations

The OU1 cap design efficiently addresses the spatial distribution of PCB contamination for areas in which capping is allowed. Water depth is also a critical design parameter for two major reasons. First, the post-cap water depth must be at least 3 feet for navigability (OU1 ROD), and armoring is required for cap areas with shallow water depths due to the potential erosive forces from boat propellers (prop wash). Erosion characteristics of extreme wind-wave and flow events also affect cap design.

Selection of potential cap areas is highly associated with the spatial distribution of the sediment contamination and available water depths, as interpreted form the 3D model (GMS-SED) and spatial database (ArcGIS). The horizontal resolution of the spatial database was greater than 30 ft. Further details are presented in the OU1 Cap Design Document, Revision 2 (Foth 2007).

Cap design criteria for OU1 also include several exclusion conditions. Restrictions to capping will be presented first, followed by attributes of PCB concentrations and factors influencing the erosive stability of the cap. Further discussion is also given to the coordination of the proposed capping plan with other elements of the OU1 Plan.

2.1.1 Restricted capping areas for OU1 Plan

Capping contemplated in the contingent remedy will <u>not</u> be permitted in certain areas of OU1:

- No capping in areas of navigation channels (with appropriate buffer zone).
- No capping in areas of infrastructure such as pipelines, utility easements, bridge piers, etc (with appropriate buffer zone).
- No capping in areas with PCB concentrations exceeding Toxic Substances Control Act (TSCA) levels.
- No capping in shallow water areas (bottom elevations which would result in a cap surface at elevation greater than -3ft chart datum for OU1 without prior dredging to allow for cap placement.

Of the infrastructure identified to date in OU1, only the Highway 441 bridge and the submerged pipeline immediately south of the bridge are located near proposed cap areas. Exact infrastructure locations will be more precisely identified during future design and remedial action phases of the project.

2.1.2 Sediment characteristics of proposed OU1 cap areas

Values for the surficial PCB concentration (the average concentration in the top 8 inches of soft sediment) are less than 10 ppm in all of the proposed cap areas, and less than 5 ppm in 97% of the areas. The maximum PCB concentrations in the 1.0 ppm prism range from 1.2 ppm to 49.1 ppm. Roughly 90% of the proposed cap areas have maximum PCB concentrations below 25 ppm and 72% of the areas have maximum PCB concentrations below 10 ppm.

The total proposed cap area is estimated as 112 acres. The 1 ppm isopach (sediment depth expected at the deepest extent of sediments with a concentration of 1 ppm or greater) ranges from 0.1 ft. to 2.8 ft. for the proposed cap areas. If dredged to the 1 ppm isopach, the cap area would represent 265,830 cubic yards with an average cut of roughly 1.5 ft. The sediments within the isopach are generally soft, with approximately 80% of the areas having an average percent solids ranging from 15-20% solids. Approximately 94% of the proposed cap areas fall within the OU1 Sub-areas E1, E2, and E3-South (E3S). These areas are primarily deep and depositional.

2.1.3 Water depths and bed shear characteristics of proposed OU1 cap areas

Final water depths reported here are based on consideration of the low-water datum, the proposed cap thickness (13 inches), and without consideration of expected consolidation of the underlying sediment or cap media. Consolidation is addressed separately. Final water depths in the proposed cap areas are expected to range from 6.0 ft to over 20 ft. Roughly 75% of the proposed cap areas have post-cap water depths greater than 7.6 ft. and 50% of the areas have post-cap water depths greater than 8.4 ft.

The proposed OU1 cap areas are primarily depositional because the fluid shear stresses acting on the sediment bed (bed shear stresses) are low. Areas with higher sediment PCB concentrations at depth tend to be more depositional in nature. The upper sediment bed is composed of soft, organic silts with moderate plasticity. Under high bed stresses, these sediments would erode. However, more than 90% of the proposed cap areas have soft sediment thicknesses of 3 feet or more, and 50 % of the areas have thicknesses of 7 feet or more.

The placement of armored caps is expected to greatly increase the erosional resistance of the sediment bed. However, erosion resistance for the proposed cap areas is evaluated on the basis of the resistance to extreme events, primarily 100-year flow conditions, 100-year combined wind-wave and current events, and prop wash events.

Resistance to prop wash is considered with a prop wash model. Prop wash considerations, including selection of design vessels and expected usage characteristics, are handled stochastically, with a Monte Carlo modeling approach. Model outcomes for stable particles at a given probability level are provided for a given water depth. Outcomes of the prop wash model were a major factor in limiting capping areas to areas in which the final water depth would be 6.0 ft. or greater. Further details of the prop wash model are addressed below (Section 3).

Cap erosion stability for the less turbulent wind-wave and 100-year flow event forces are evaluated from model-estimated bed shears at all proposed cap locations. Bed shear stresses were calculated using hydrodynamic and wind-wave models (Baird 2006 and Baird 2007). Wind-wave bed shear stresses for a 100-year return period were estimated from combining waves generated from hourly winds with a 50-year return period and daily flows with a 2-year return period. Maximum bed shear stresses in the proposed cap areas range from less than 10 dynes/cm^2 (1.0 Pa) to less than 40 dynes/cm^2. More than 99% of the proposed cap areas had maximum bed shear stresses less than 30 dynes/cm^2 and 90% of the areas had maximum bed shear stresses less than 22 dynes/cm^2. In comparison, all proposed cap areas had bed shear stresses less than 10 dynes/cm^2 for simulation of a 100-yr flow event.

Particle stability of the proposed cap media is discussed below (Section 3), in terms of resistance to expected bed shear stresses from extreme events of prop wash, wind-wave, and 100-year flow.

2.2 Coordination of capping activities with other OU1 Plan elements

GW Partners does not anticipate that dredging will occur simultaneously with capping operations in OU1. In fact, in order to meet capping restraints and operational efficiencies, some areas previously considered as potential cap areas were dredged in 2007. Accordingly, a detailed analysis of the required isolation distance between dredging and capping operations is unnecessary. The proposed placement of sand cover, however, may be implemented in close coordination with the capping plan.

The representations of OU1 Optimized Remedy action areas for dredging, capping, sand cover, and natural recovery are currently based on an efficient ArcGIS representation. Although the footprint of the proposed capping areas is generally contiguous, the current representation of the proposed cap areas may appear rough, with jagged edges and some internal gaps. For the purposes of the OU1 Plan, the efficiency of the selection of potential cap areas (and the rapid computation of the effects of the proposed remedies) outweighs the objective to provide a cap design with smooth edges. Prior to implementation of the cap design, the proposed boundaries of the cap will be formed along smooth model contours of PCB concentrations and water depth (meeting the same criteria) and the apparent roughness of the cap design will be greatly reduced. Further details regarding geometric refinement are presented in the OU1 Cap Design Document, Revision 2 (Foth 2007).

2.3 Verification and monitoring

A series of sampling, quality assurance and control measures will be taken to meet cap design criteria as well as applicable rules and regulation. Cap placement quality assurance measures will consist of testing placement accuracy and precision on dry land, physical measurements to verify the proper placement thickness of each layer, and statistically valid measurements to assure a minimum placement thickness of each layer in at least 90% of the capped areas. Measures will be taken to address any capped portions that are found to have cap layers less than the minimum protective thickness.

Further details regarding recommended verification and monitoring procedures are presented in the OU1 Cap Design Document, Revision 2 (Foth 2007).

3. Proposed Cap Design Layers and Cap Media Selection

The proposed cap design is based on the characteristics of the proposed OU1 cap areas (Section 2), cap design guidance, a multi-barrier approach for selecting cap layer thicknesses, and selection of cap media that provide effective formation of cap (mixing layer), effective layering (filter criteria), and erosive stability (armor layer). The potential for ice scour and hydrodynamic modification should be considered. In addition, geotechnical considerations regarding consolidation, slope stability, and foundation strength should be addressed.

3.1 Multi-barrier approach and conceptual cap design layers

An engineered cap is designed to provide long-term, in situ containment of contaminated sediments and long-term stability against physical attack in the LLBdM environment. Engineered cap design is based on a conservative, multi-barrier approach (Palermo, *et al.* 1998b, Palermo, *et al.* 2002). The functions of the conceptual layers of the cap are:

- An operational thickness to address sand-sediment mixing (formation of a filter layer) needed to establish the cap over soft sediment (T_m)
- A chemical isolation layer to contain contaminants in the underlying sediment (T_i)
- A bioturbation layer to provide physical isolation of burrowing benthic organisms (T_b)
- A consolidation layer to correct for any consolidation of the cap media (T_c)
- An erosion layer to provide sufficient thickness and an appropriate gradation of media on the top of the cap that is resistant to erosion (T_e)

Operational considerations, including the mixing layer (T_m), filtering and geotechnical foundation for armored erosion layers, media placement accuracy, and other processes, may also require additional media thickness (T_o).

The multi-barrier approach is generally additive, although some of the conceptual layers can be combined under certain conditions. For the settings of OU1 (Palermo, *et al.* 2002), the bioturbation and erosion layers (excluding any additional armoring requirements) can be combined into one bioturbation/erosion layer ($T_{b/e}$). For low contaminant concentrations, where very thin layers for chemical isolation are suitable, the chemical isolation layer can be combined with the underlying mixing layer (T_m). If capping were to be proposed for areas with higher PCB concentrations, a layer of uncompromised sand may be needed for additional chemical isolation.

For granular cap media with a low fines content, no consolidation of the cap media is expected ($T_c = 0$). However, the consolidation of underlying soft sediment may be significant and the sediment pore water expressed from that consolidation is considered as part of the chemical isolation design.

A summary of proposed OU1 cap media selection and thicknesses for different sediment and erosion conditions is presented in Table A-1. For all cap conditions, a segment of the operational thickness of 3.0 inches is assigned to deal with sand-sediment mixing. For low PCB concentrations (e.g., average PCB concentration in the top 8 inches is less than 10 ppm), the mixing layer is expected to provide adequate chemical isolation and the combined thickness of the cap is as follows:

$$T = T_{b/e} + T_o$$

As mentioned above, chemical isolation is incorporated into a mixing layer (part of the operational thickness). Since the minimum thickness of the bioturbation layer is generally considered 4 inches and the minimum operational (mixing) layer is generally considered 3 inches, the minimum design thickness of the applied cap could be considered as 7 inches. The cap thickness is 13 inches with overplacement (3 inches overplacement for each media type).

Further details regarding the main layers of the cap design are addressed below.

3.1.1 Mixing layer

For all cap conditions, a segment of the operational thickness of 3.0 inches is assigned to deal with sand-sediment mixing. The mixing layer is the equivalent amount of applied sand needed to establish a clean sand layer. Although sand may penetrate the sediment to sediment depths greater than 3 inches, the mass fraction of sand is expected to fall off relatively quickly from the sand-sediment interface and the amount of applied sand is expected to be less than 3 inches for the proposed OU1 cap areas. The selection of the mixing layer was considered appropriately conservative as evaluations from the 2007 Cap Placement Test in OU1 confirmed very thin mixing layers (i.e, approximately one-inch thick mixing layer). In addition, a three-inch mixing layer was selected for similar sediments addressed by the proposed cap for the OU2-5 design (Shaw and Anchor, 2006). Further details and results are presented in the OU1 Cap Design Document, Revision 2 (Foth 2007).

Table A-1
Cap Layer and Total Thickness for Proposed OU1 Cap Areas

Layer	Category for Thickness	Cap Media	Design Thickness (in.)	Design Thickness with Operational Overplacement (in.)
Bioturbation / Erosion Layer	Operational, overplacement	armor stone	0	3
	Bioturbation / Erosion		4	4
Chemical Isolation Layer	Operational, overplacement	sand	0	3
	Chemical Isolation / Operational Mixing Layer		3	3
Total Thickness			7	13

Note: Final operations overplacement allowance will be specified in the work scope and agreements with the selected contractors(s).

3.1.2 Chemical isolation layer

A chemical isolation model has been used to verify that 1 inch of sand is protective to chemically isolate sediment PCBs from benthic organisms ($T_i \leq 1.0$ inch). The chemical isolation layer is considered to be biologically inactive, providing a physical, diffusion barrier from the bioturbation-erosion layer. This model is based on conservative assumptions regarding surface PCB concentrations, total organic contents in the underlying sediment and in the benthic layer, and allowances for limited advection through the cap. Chemical isolation model calculations were run for the peak surface PCB concentration of 10 ppm, as well as with consideration of higher PCB concentrations at depth. Although upward flow from the sediments to the cap is not expected, a conservative analysis of regional groundwater gradients and cross-section hydrogeologic modeling was used to develop an upper-bound estimate for upward groundwater advection (specific discharge of 16.3 cm/yr). Chemical isolation calculations were then used to verify that a 1-inch chemical isolation layer was protective in terms of limiting PCB mass fluxes from the underlying sediment and for maintaining low PCB concentrations in the benthic layer, in perpetuity.

The pore water expected to be expressed through the cap due to the consolidation of the underlying sediments was also considered in the evaluation of the chemical isolation layer. Given the very low concentrations of PCBs expected in the pore water and some sorption from the cap media itself, a very thin layer of sand (on the order of 1 mm) was found to provide adequate isolation from the consolidation pore water. Therefore, no additional thickness for the chemical isolation layer was required to address the consolidation concern. Consolidation of the cap media itself was also considered negligible.

Details on chemical isolation modeling and groundwater advection analysis are presented in OU1 Cap Design Document, Revision 2 (Foth 2007).

3.1.3 Operational overplacement for chemical isolation / mixing layer

Cap guidance documents (Palermo, et al. 1998a and Palermo, et al. 1998b) address the consideration of overplacement as a portion of the operational thickness. This portion of the cap guidance effectively increases the operational thickness of caps in order to assure a minimum placement.

A chemical isolation layer of 1 inch or less, considered to be combined within the 3-inch operational mixing layer, poses some difficultly with respect to monitoring and verification of chemical isolation. However, potential overplacement of sand, forming an observational layer of unmixed sand over the mixing layer, can be documented by field measurements.

The targeted sand overplacement allowance of 3 inches is provided primarily as assurance to meet the minimum design thickness of applied sand. A final operations overplacement allowance will be specified in the work scope and agreements with the selected contractors(s). Results from the 2007 Cap Placement Test will be used to help determine that 3 inches is a suitable overplacement amount for applied sand.

3.1.4 Bioturbation-Erosion layer

The bioturbation-erosion layer thickness is set by a conservative selection for the bioturbation thickness, or 4 inches. This thickness is supported by a significant body of evidence developed for soft sediments. The thickness is also consistent with the selection from the OU2-5 cap design (Shaw and Anchor, 2006). An upper layer of the sediment cap is expected to become biologically active, but only after years of nutrient enrichment and organic matter flow into the (interstitial) pores of coarse cap media.

Aspects of the granular media and the availability of uncapped soft sediment at nearby locations are expected to limit bioturbation within cap areas. A more likely scenario would be that organic, soft sediments continue to deposit on top of the armor, and the biological active zone would be established within this freshly deposited layer, with limited biological penetration into the armor.

The erosion portion of the bioturbation-erosion layer is not limiting, because the thickness required for erosion protectiveness is generally considered to be at least 2 times the stable median particle diameter (D_{50}) meeting erosional resistance criteria, and at least 1.5 times the maximum stone diameter (D_{100}) (Palermo, et al. 1998a, Appendix A). The D_{50} of the armor is expected to be less than 0.75 inch and the D_{100} is expected to be less than 1.3 inch, so the thickness required for erosion protectiveness is less than 2 inches.

The design thickness for the bioturbation-erosion layer is 4 inches, with the intended application of at least 4 inches of armor media that provides suitable erosional resistance. However, for purposes of verification, the cap criteria for the bioturbation-erosion layer may be satisfied for a cap area that is shown to have a bioturbation-erosion layer thickness of at least 4 inches, suitable armor media on top, and a suitable thickness of armor media. For example, if the minimum armor thickness required is 1.5 inches (with armor media $D_{100} \leq 1.0$ inch and $D_{50} \leq 0.75$ inch), the cap criteria would allow a 4-inch bioturbation-erosion layer to consist of 2.5 inches of sand (lower portion) and 1.5 inches of armor (upper portion).

3.1.5 Operational overplacement for bioturbation-erosion layer

An overplacement allowance of 3 inches is targeted primarily as assurance to meet the minimum design thickness of applied armor media. A final operations overplacement allowance will be specified in the work scope and agreements with the selected contractors(s). Results from the 2007 Cap Placement Test will be used, in part, to demonstrate the suitable overplacement amount for armor media.

3.1.6 Summary and discussion of minimum cap thickness

The intended minimum cap thickness is 7 inches, with 3 inches of applied sand and 4 inches of armor media. An overplacement allowance of 3 inches is expected for each media layer. A final operations overplacement allowance will be specified in the work scope and agreements with the selected contractors(s).

For the purposes of verification of the minimum cap protective thickness, it is important to note that the criteria of the cap design is expected to be met if the total applied thickness of the cap is at least 7 inches, there is an adequate thickness of sand available to assure chemical isolation, 4 inches of cap media are available above the chemical isolation layer for a bioturbation-erosion layer, the armor layer is suitably thick and the armor layer media provides suitable erosional resistance.

For the proposed OU1 cap design, it is expected that overplacement will be a natural outcome of the cap design, project specifications, and cap placement contractor agreement. The average and maximum overplacement will be dependent on the placement method and project specifications. Average expected overplacement is included in the cost estimate, and is used to estimate post-cap water depths. Measures will be taken to address any capped portions that are found to have cap layers less than the minimum protective thickness.

3.2 Selection of cap media

The proposed cap design includes two separate media, sand used to form the combined mixing layer and chemical isolation layer, and armor (stone) used to form the bioturbation-erosion layer. In addition to meeting media requirements for the individual layers, the sand and armor media must also pass media gradation filter criteria so that the media do not mix appreciably during or after placement. In order to reduce turbidity during placement of the cap media, the cap media should be clean and relatively free of fines.

The selected media are based on demonstrated usage within the 2007 Cap Placement Test. Further details regarding media selection, evaluations of the performance of media selected for the 2007 Cap Placement Test and further specifications for cap media are addressed in the OU1 Cap Design Document, Revision 2 (Foth 2007).

3.2.1 Sand gradation specifications

The sand selected as the lower cap media is expected to be consistent of ASTM C33 fine aggregate (concrete sand), which is the poorly graded sand used that was used for the 2007 Cap Placement Test Demonstration Project. The D_{85} of the sand is roughly 1.55 mm, the D_{50} is roughly 0.49 mm, and the D_{15} is roughly 0.28 mm. The coefficient of uniformity (Cu) is 2.3 and the coefficient of curvature (Cc) is roughly 1.0 to 1.1. The fines content is less than 1%. The sand could be described as a medium-coarse, poorly graded sand with a low fines content.

The sand media has been demonstrated to be compatible with the fine, soft sediments in areas of the 2007 Cap Placement Test. The mixing layer was observed to be less than 3 inches and a clean sand layer was present above the mixing layer. Filter criteria (discussed section 3.2.3) would not be applicable to this mixing layer.

3.2.2 Armor stone gradation specifications

The armor media selected as the upper cap media is expected to be consistent with the armor stone (ASTM #467) used for the 2007 Cap Placement Test. The D_{85} of the stone is roughly 30 mm (1.2 in.), the D_{50} is roughly 17 mm (0.67 in.), and the D_{15} is roughly 7 mm. The maximum particle size is 32 mm (1.25 in.). The coefficient of uniformity (Cu) is 3.2 and the coefficient of curvature (Cc) is roughly 1.5. The armor stone (a well graded gravel by USCS description), similar to the sand, has a low fines content.

3.2.3 Filter criteria

Filter criteria are used to select compatible sand and armor stone media. Filter criteria are used to reduce the potential for internal erosion of the sand into the armor layer, due to temporary currents (from waves and other sources) within the armor stone layer. Poorly selected media, failing the filter criteria, may result in mixing of the gravel and the sand. This may result in a deterioration in the erosional resistance of the armor layer.

One of filter criteria states that the D_{15} armor stone size should be no greater than 5 times the D_{85} sand size. Since the measured D_{85} of the sand is 1.55 mm, the D_{15} of the armor stone should be no greater than 7.75 mm (0.31 in.). The D_{15} of the armor media is 7 mm. so this filter criterion is met. Other applicable filter criteria are also met and these are addressed in the in the OU1 Cap Design Document, Revision 2 (Foth 2007).

3.2.4 Stability criteria for armor stone

The selected armor stone for the purposes of the cap design has been shown to meet stability criteria identified from analysis of prop wash, the 100-year flow event, and the combined 100-year wind-wave and flow events. The prop wash model considers a dynamic stability model of the armor stone, while particle stability for the wind-wave and

100-year flow event analyses is based on the Shield's curve (US Army Corps of Engineers, 1995).

3.2.4.1 Stability criteria for armor stone – prop wash model results

The Lower Fox River OU2-5 Design Team worked extensively over the past 2 years with the A/OT in the selection and evaluation of an appropriate Prop Wash Model for the Lower Fox River. It is our understanding the A/OT has accepted the JETWASH model, with certain modifications, as documented in the Coast Harbor & Engineering Technical Memorandums, dated August 17, 2007.

Given the extensive prop wash work completed by the OU2-5 Design Team and the A/OT, GW Partners has decided to accept the basis of this work for application at OU-1.

Separate boat surveys were completed for OU1 and OU2-5. As a brief summary, the OU2-5 boat survey (which included Lake Winnebago and the Lower Fox River to the Bay of Green Bay) showed that the OU2-5 survey consisted of more vessels in the larger size range than the OU1 boat survey. In order to be consistent and protective over time, the OU2-5 boat survey will conservatively be used for the OU1 Prop Wash Cap Design work.

Prop wash results for use at OU1, using the OU2-5 Boat Survey, and the agreed to JETWASH model inputs, as shown on Figure A-1. These results show stable grain size (as D_{50} diameters), for the armor component of the cap, at various water depths and at various Monte Carlo confidence outputs.

The 13-inch engineered cap at OU1, with an over-placement allowance, will consist of 6-inches of sand and 7- inches of armor (minimum design thickness of 3-inches of sand and 4-inches of armor). The selected grain size of the armor layer, at a given depth, varies depending on which modeled output from the Monte Carlo analysis is applied for the Lower Fox River.

For the design basis at OU-1, the model results show that the following armor stone sizes would be required to achieve the associated prop wash Monte Carlo output:

Water Depth (ft.)	Acres	Armor Stone (D50)	Monte Carlo Output
6.0-6.5	5.1	0.6"	90%
6.5-7.0	8.2	0.5"	95%
7.0 +	99.0	0.25"	95+%

The 6.0-6.5 post-cap water depth, where GW Partners is proposing a 90% Monte Carlo output, represents a small area (5.1 acres), in a central portion of LLBdM, of the total proposed 112 capping acres. All told, 107 acres of the 112 acres (95% of the area) will be capped with armor stone at or exceeding the 95% model output criteria. In essence, 95% of the area will exceed 95% of the Prop Wash model output. However, these values assume no consolidation of the soft sediments under the placed material. Considering

consolidation, we believe nearly 100% of the proposed cap areas will meet the 95% model output criteria.

Cap construction based on the design will include media selection that will need to be reviewed and approved by the Agencies on a case-by-case/area-by-area basis. When costs associated with media placement (media costs plus placement-related costs) for armor media with a larger D_{50} are virtually the same as the media with a minimum D_{50} required for erosional resistance, the larger stone will be selected preferentially.

3.2.4.2 Stability criteria for armor stone – wind-wave and flow model results

As discussed in Section 2.1.3, the maximum, wind-wave bed shear in the proposed OU1 cap areas was less than 40 dynes/cm^2 (4.0 Pa), and less than 22 dynes/cm^2 in more than 90% of the areas. A particle diameter of 5 mm is expected to be stable under 40 dynes/cm^2 and a particle diameter of 3.1 mm is expected to be stable under 22 dynes/cm^2.

For OU1, wind-wave effects generally lead to higher bed shear than the 100-year flow event. Hydrodynamic modeling of the OU1 cap regions showed that 100-year flow events produce bed shear stresses less than 10 dynes/cm^2. Under these bed shear conditions, a coarse sand with a particle diameter of roughly 2 mm would be stable.

3.2.4.3 Stability criteria for armor stone – summary

For the limiting post-cap water depth of 6.0 ft., stable stone diameters from the prop wash analysis (20 mm at the 95th percentile, 15 mm or 0.6 in. at the 90th percentile) were most critical. At depths of 7.6 ft. or greater (75% of proposed cap areas), stable particle diameters from the prop wash analysis were less than 4 mm. At intermediate depths (7.6 ft) and deeper, wind-wave forces may be most critical (stable diameter less than 5 mm for all areas). Bed shear conditions for the 100-year flow event were not critical.

The OU1 Design Supplement is currently based on the selection of armor stone with a D_{50} of 15 mm (0.6 in.). With some consideration of consolidation, this D_{50} is expected to meet prop wash conditions at the 95th percentile for all areas. Without consideration of consolidation, this D_{50} is expected to meet prop wash conditions at the 90th percentile for all areas and at the 95th percentile for 95% of the proposed cap areas. For 75% of the proposed cap areas with water depths greater than 7.6 ft., the stable particle diameter of 5 mm is considered to be appropriately conservative.

3.3 Consideration of ice scour

During the winter months, LLBdM will be partially covered with ice. Special considerations need to be given to various ice related processes in the cap design as they will affect the long term stability of the cap. Depending on the characteristics of a particular lake system shallow sediments or sediment caps may be susceptible to the erosive forces of ice flows during ice breakup. As the main ice mass covering a lake thaws and fractures during periods of warm weather, wind and other hydrodynamic forces have the potential to move thick sheets of ice to shallow near shore areas causing erosion of bank and sediments. Ice jams in river systems also have the potential to alter normal flow velocities and cause increased erosion of sediments or sediment caps.

Finally, frazil and anchor ice has the potential to form when fast flowing water is super cooled. These latter ice formations have the potential to dislodge and erode sediment and sediment caps.

GW Partners contracted with an expert to evaluate effects of ice on cap design proposed for OU1. GW Partners' technical consultant, George Ashton, evaluated ice jamming at the old railroad trestle and the 441 bridge, and concluded that ice jamming associated with ice breakup does not occur in LLBdM. Ice jamming at the old railroad trestle is highly unlikely. The maximum likely velocity there for a very high winter flow of 11,100 cfs is only about 0.82 fps. It is generally understood that the threshold velocity at which ice pieces are swept under an ice cover and begin forming a jam is about 2 fps. Thus ice pieces may lodge against the trestle but will remain at the surface and no jam would form. At the 441 bridge the velocities are even lower and estimated at less than 0.5 fps for the same conditions. Again, large floating ice sheets may lodge against the piers but would not submerge to form a jam.

There is a slight possibility of limited frazil ice to be generated during cold periods, immediately down stream of the dams, at the southern reaches of OU1. Considering the average water flow velocities expected during the winter months is relatively low, significant accumulation or downstream migration of frazil ice in the vicinity of the capped areas is highly unlikely. The proposed cap areas are over 5,200 feet from the areas where frazil ice potentially could be generated. Other ice processes that could potentially pose a hazard to capped areas were examined including the physical blockage of the flow cross section by ice cover thickness anticipated during winter months. These types of blockages increase the shear stress on the river bed, relative to the same discharge during open water periods. The shear stress on the river bed caused by these blockages is much less than the bottom shear stress at high discharges associated with a 100-year return flow. The overall conclusion of the ice scour evaluation is that ice conditions do not change the selection of capping materials in the capping areas (Ashton 2006).

Further details regarding ice conditions and the potential for ice scour in OU1 are addressed in the OU1 Cap Design Document, Revision 2 (Foth 2007).

3.4 Consideration of water depth and hydrodynamic modification

The flow of the Fox River through OU1 is controlled by upstream and downstream dams and generally well understood (Retec 2002). In general, hydrodynamic modifications from dredging, sand covering, and capping in OU1 are expected to be minor, even for 100-year flow events. The geometric changes made to LLBdM cross-section from dredging and capping activities are relatively minor. Modeling of hydrodynamic and wind-wave conditions was performed with expected final (after implementation of OU1 Plan). Dredged areas in southern and south-central portions of OU1 have resulted in a slight local increase in the carrying capacity and proposed cap areas result in a slight local decrease in carrying capacity. Areas that have higher river velocity and higher bed stresses generally have low PCB concentrations, due to past erosion and limited fine sediment deposition. So, as a natural consequence of the contamination loading history, past flow events, and sediment-contamination characteristics, a large portion of OU1 action areas are isolated from the more critical flow areas of OU1. As a result, hydrodynamic effects from the expected changes in water depth in OU1 are expected to be minor.

The net change in water depth from conditions prior to 2004 to conditions upon completion of the Optimized Remedy are estimated to be 0.8% more water volume in OU1 over the 499 acre entire 1 ppm RAL region. Considering the entire 1363 acre OU1, the effect will be significantly less than 0.8%. The final water depth above capped areas will be at least 6 feet deep.

Further details regarding estimated area distributions for water depths in OU1 are addressed in the OU1 Cap Design Document, Revision 2 (Foth 2007).

3.5 Consideration of consolidation of underlying sediment

A large portion of the proposed OU1 cap areas have thick deposits of soft sediments (soft sediment thicknesses of 4 feet or more with percent solids contents generally less than 20%). Consolidation of the sediment underlying the proposed cap areas is expected to be significant. The increase in effective stress from the applied 13-inch cap is expected to be roughly 60 psf, leading to 12 inches or more of consolidation for many of the proposed cap areas. Areas with soft sediment thickness less than 6 ft. are expected to have less consolidation, and consolidation for areas with sediment thickness greater than 6 ft. may be overestimated due to the lack of consolidation data at greater depths. Further details with respect to measured consolidation of capped areas is addressed from analysis of the 2007 OU1 Cap Placement Test , and further details and discussion of consolidation is presented in the OU1 Cap Design Document, Revision 2 (Foth 2007).

3.6 Consideration of shear strength of capped OU1 sediment

An evaluation of sediment shear strength, slope stability, and the potential for bearing (punch-through) was made for proposed OU1 cap areas. In addition, the stability of the soft sediment base materials was inspected as part of the 2007 OU1 Cap Placement Test. While the shear strength of the soft surface sediments is particularly low, the sediment shear strength is expected to be adequate to prevent slope failure in the proposed OU1 cap areas. Capping will be limited to slopes less than 5:1 (horizontal to vertical distance). No slide or sub-grade failures were observed as part of the 2007 OU1 Cap Placement Test and several observations were made indicating acceptable resistance to a punch-through failure.

In general, the shear strength of the sediment underlying the proposed cap areas is expected to increase as it consolidates. During a brief period after loading, the undrained shear strength is expected to be low, and possibly unsuitable. However, as the pore pressures in the underlying sediment are significantly dissipated over a period of days to weeks, the sediment is expected to strengthen significantly. During capping, monitoring is planned to investigate potential movement of underlying sediment. Evidence of any slope or foundation failures will be cause for delaying cap placement operations. Further details regarding geotechnical stability considerations are presented in the OU1 Cap Design Document, Revision 2 (Foth 2007).

3.7 Consideration of Liquefaction

The issue of liquefaction falls within the general topic of erosive and physical integrity of the cap. A review of the potential for wave-induced liquefaction was addressed as part of the wind-wave report (Baird, 2007, Section 4.2), and further discussion will be provided in the forthcoming document, OU1 Cap Design Revision No. 2 (Foth, 2007).

Baird (2007) had noted that the potential for a liquefaction failure is limited, but mentioned that the "possible interaction between wave-induced pore-water flows and the native material under the cap may be another issue to consider, however, this is more a question of appropriate filtering design between the layers." The discussion of filter criteria and the assessment of a sand-sediment mixing layer will be provided in the forthcoming Cap Design Revision No. 2.

Liquefaction would be expected occur only if the effective shear strength of the sediment falls below a critical limit value, due to a build-up of pore pressures within the sediment. While pore pressures increase with wave height, so does the confining pressure. So, the hydrostatic pressure wave does not induce a change in effective stress within the sediment. A body force, such as prop wash or wave-generated bed shear or seismic event, is needed to suddenly increase pore pressures within the sediment. It is the resulting body shear force, not the hydrostatic pressure itself, that leads to the buildup of pore pressures from waves. Because of erosion protection issues, the proposed OU1 cap is at final water depths greater than 6 ft. and in areas with low bed shear.

Dynamic, differential pressures from waves (peak to valley) can also lead to an oscillatory bed shear, although seepage within the more permeable (upper) regions of the cap is expected to dampen bed pressure oscillations. Because studies have shown that the allowable wave height increases with consolidation time (De Wit and Kranenburg 1997, as cited by Baird 2007), the most vulnerable periods for the cap would seem to be during placement and, possibly, during storms shortly after cap placement. The dynamic, differential pressures and other stresses brought on during cap placement are likely most relevant to OU1. Therefore, the initial post-placement monitoring (occurs in an area shortly after cap placement) will be able to capture whether a liquefaction failure has occurred. In addition, because of the timing of placement and storms that may induce failures, failures are likely to be localized and might be corrected by additional capping.

Given that there is a lack of guidance regarding engineering cap design and liquefaction, and that there is little evidence that liquefaction failures have been a problem at other capping sites in the US, a more thorough geotechnical evaluation of the potential for liquefaction failures in OU1 was not conducted. This judgment was shaped in part from the project team's experience to date in OU1 with capping and sand cover over very soft sediments.

In summary, while liquefaction failures are not expected, such failures, if they do occur, are likely to be observed during and soon after cap placement. However, the vulnerability of the capped areas to liquefaction is expected to decrease with time after placement. If liquefaction failures are detected, the contingency plan will address corrective actions, which may include additional capping or adjustments to the cap design.

4. Cap Placement, Monitoring and Quality Assurance Plan

4.1 Method of Cap Placement

A hydraulic transport and mechanical broadcast-type spreading system for sand placement was tested during the 2004 RA. The sand placement system was designed to minimize mixing the sand capping material into the sediment. For placing the sand portion of the OU1 Optimized Remedy caps, a transport/placement process similar to the 2004 operation is anticipated. A process similar to that used for sand placement is envisioned for transporting and placing the gravel/stone portion of the engineered armored caps. In addition, methods for cap placement are currently also being evaluated on the basis of a 2007 Cap Placement Test carried out in three areas in Sub-area E2 (Foth, 2007c). The 2007 Cap Placement Test involves a detailed process plan for material specifications, stockpile management, slurry delivery to the placement barge, effective broadcast methods of the capping equipment, accurate positioning and position controls, and site logistics to maintain performance criteria of the project. Details and objectives for the capping demonstration are discussed in the 2007 Cap Placement Test Plan (Foth 2007c).

A variety of controls are in place to assure effective capping and to reduce environmental impacts from the capping. These include metering controls, Dredgepack and Wonderware software, navigational control, media testing to assure clean media is placed, turbidity monitoring of the water column near the capping areas, and a variety of other quality control and monitoring strategies. Best management practices will be used for cap placement operations, such as working in a upstream to downstream manner, using high-grade mufflers to limit engine noise, and clear chain-of-command procedures for emergencies and project communications.

General quality control steps (measures before and during placement to meet design goals) are summarized above and quality assurance steps (measures during and after placement to verify that minimum design criteria were met) are presented in section 4.2. Further details regarding both will be presented in the Cap Design Revision No. 2.

4.2 Production Rates and Quality Assurance (CQAP)

The current production rate estimated for placement of both the sand and armor stone portions of the cap is approximately 50 cy/hr. Experience gained from the 2007 cap placement test will be used in the final design of the cap. The armoring gravel will be placed in a separate operation following the sand placement, but within the same season as the sand placement. Sand and armor stone are planned to be placed in separate, single lifts.

Cap placement quality assurance measures will consist of the following:

- Testing placement accuracy and precision on dry land
- Physical measurements to verify the proper placement thickness of each layer
- Statistically valid measurements to assure a minimum placement thickness of each layer in at least 90% of the capped area

An evaluation of the performance of the 2007 Cap Placement Test is ongoing. Further details regarding quality assurance measures and reporting of the 2007 Cap Placement Test will be reported in the Cap Design Revision No. 2 (Foth 2007).

4.3 Monitoring, Maintenance and Contingency Response Plan

A long-term monitoring, maintenance and contingency response plan, including repair (as necessary) of damaged capped areas, is part of the Optimized Remedy and will be prepared to ensure the integrity and reliability of the *in-situ* cap. The objectives of the cap monitoring program will be to detect and evaluate any physical changes in the cap that would potentially reduce protectiveness over time. The long-term cap monitoring program will include the following components:

- **Bathymetric Surveys** – Bathymetric surveys will be completed to evaluate the physical integrity and thickness of the capped areas. These surveys will be conducted initially post-construction and then at specific time intervals (along the same transects) to identify potential areas of significant erosion, deposition, or consolidation.
- **Coring and Surface Grab Sampling** – Coring will be conducted to visually inspect the cap and cap thickness. Coring will also be conducted to supplement any elevation data discrepancies obtained from the bathymetric surveys that may indicate significant elevation loss. Follow-up sediment cores will be collected to determine whether the elevation loss is a result of erosion or settlement based on visual evaluation of the cores, considering core compaction.

The cap monitoring and maintenance plan will identify the specific details regarding frequency, location and type of sampling. A contingency response plan will be prepared in conjunction with the Long-Term Monitoring and Maintenance Plan that will identify specific criteria to be monitored and possible outcomes of the monitoring. Evaluation criteria will be identified and a range of responses/actions will be included depending on the results of the evaluation. The Agencies will also evaluate cap performance and the need for and scope of continued cap monitoring and maintenance as part of the five-year CERCLA review process.

References:

Baird & Associates, 2006. *Numerical Model Assessment of Bed Shear Stress for the 100-year Return Flow, Little Lake Butte des Morts, Fox River*. Prepared for Foth & Van Dyke and Associates, Project No. 11172.000, November, 2006.

Baird & Associates, 2007. *Numerical Model Assessment of Bed Shear Stress for Wind-Waves and Flows on Little Lake Butte des Morts (OU1), Fox River*. Prepared for Foth Infrastructure & Environment, LLC., Project No. 11172.010, June 29, 2007.

Coast & Harbor Engineering. "Prop Wash Technical Memorandums, Nos. 1-6". August, 17, 2007.

Foth Infrastructure and Environment, 2007. "OU1 Cap Design Document, Revision 2", in preparation, expected submittal December 2007.

Palermo, M., Maynord, S., Miller, J., and Reible, D., 1998a. "Guidance for In-situ Subaqueous Capping of Contaminated Sediments," EPA 905-B96-004, Great Lakes National Program Office, Chicago, IL.

Palermo, M.R., Clausner, J.E., Rollings, M.P., Williams, G.L., Myers, T.E., Fredette, T.J., and Randall, R.E., 1998b. "Guidance for Subaqueous Dredged Material Capping," Technical Report DOER-1, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Retec Group, Inc., 2002. *Final Feasibility Study, Lower Fox River and Green Bay, Wisconsin. Remedial Investigation and Feasibility Study*. Prepared for the Wisconsin Department of Natural Resources. December 2002.

Shaw and Anchor, 2006. *Final Basis of Design Report. Lower Fox River and Green Bay Site. Brown, Outagamie, and Winnebago Counties, Wisconsin*. Prepared for Fort James Operating Company, Inc. and NCR Corporation by Shaw Environmental and Infrastructure, Inc. and Anchor Environmental, LLC. June 16, 2006.

U.S. Army Corps of Engineers, 1995. "Sedimentation Investigation of Rivers and Reservoirs," Engineering Manual, EM 1110-2-4000, Change 1, October 31, 1995.